NASA TM X-1596

ELECTRICAL CHARACTERISTICS OF A DC COMPACT ARC IN ARGON FROM 1 TO 10 ATMOSPHERES AND FROM 600 TO 1200 AMPERES

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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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ABSTRACT

Voltages across an arc have been measured in argon in the pressure range of 1 to 10 atmospheres (10^5 to 10^6 N/m^2), the current range of 600 to 1200 amperes, and with electrode separation varied from 1 to 2 inches (0.0254 to 0.0508 m). These measurements are summarized in the form of the empirical formula

$$V = 12.4(LP)^{2/3} - 1.18\, P^{2/3} + 0.0116\, I + 11.7$$

expressing arc voltage V as a function of arc current I in amperes, electrode separation L in inches, and pressure P in atmospheres, or

$$V = 6.67\times10^{-2}(LP)^{2/3} - 5.48\times10^{-4}\, P^{2/3} + 0.0116\, I + 11.7$$

where V is in volts, L is in meters, P is in newtons per square meter, and I is in amperes.

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SUMMARY

Voltages across an arc have been measured in argon in the pressure range of 1 to 10 atmospheres (10^5 to 10^6 N/m^2), the current range of 600 to 1200 amperes, and with electrode separation varied from 1 to 2 inches (0.0254 to 0.0508 m). These measurements are summarized in the form of the empirical formula

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INTRODUCTION

Work toward the development of high power compact arcs in argon has created a need for the ability to predict the electrical characteristics for these arcs. To satisfy this need, the voltage across a compact arc in argon has been measured at the Lewis Research Center. These measurements have been made in the pressure range from 1 to 10 atmospheres (10^5 to 10^6 N/m^2), in the current range from 600 to 1200 amperes, and the electrode separation range from 1 to 2 inches (0.0254 to 0.0508 m). These measurements are summarized in this report in the form of an empirical formula expressing voltage as a function of current, electrode separation, and pressure.

The current and electrode separation dependence of the voltage of a compact arc in argon has been measured and reported by Eberhart (ref. 1), Schoeck (ref. 2), and others (refs. 3 to 5). These measurements cover electrode separations extending up to 1.4 inches (0.0353 m) and currents ranging from a few to approximately a thousand amperes. Except for a few isolated points, these measurements are at a pressure of approximately 1 atmosphere (10^5 N/m^2).

APPARATUS

The equipment used in this experiment consisted of an arc chamber, an anode, a movable cathode, a power supply, and an igniter. The arc chamber, as shown in figure 1, was a cylindrically shaped, water-cooled, steel tank having a volume of approximately 1 cubic foot (0.028 cu m). Two different anodes were used. One was a 3-inch-(0.076-m-) diameter cylinder made of copper with a 1/8-inch (0.0032-m) tungsten cap. The other anode had the same size and shape, but no tungsten cap. The cathode was a copper cylinder 2 inches (0.0508 m) in diameter with a tungsten cap containing 2 percent thoria. Both the anode and cathode were cooled with high pressure water, and care was

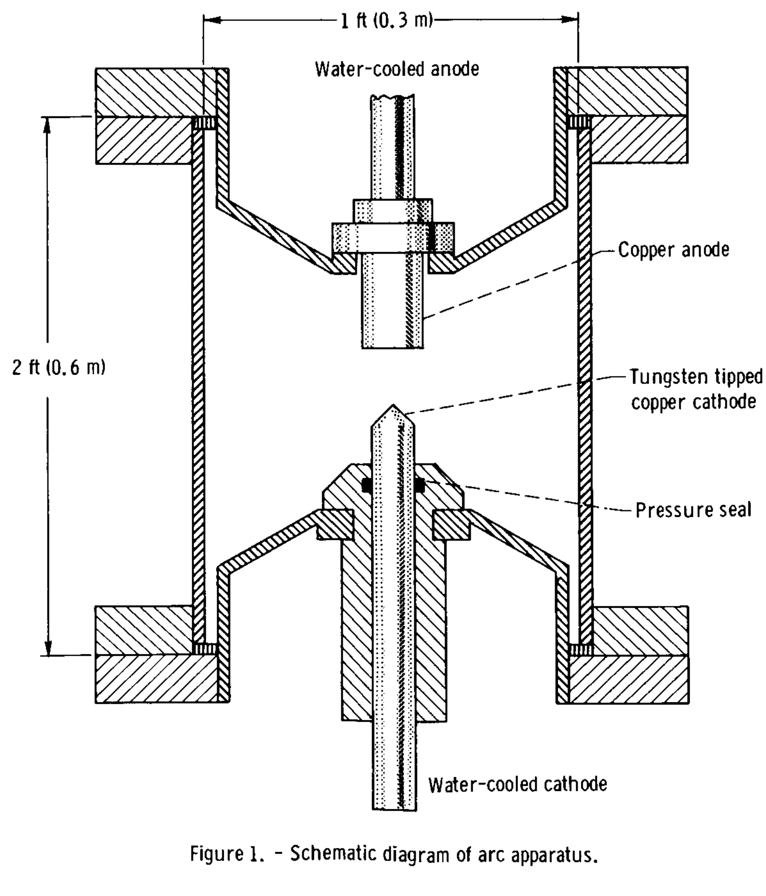

Figure 1. - Schematic diagram of arc apparatus.

taken to prevent ablation or erosion of either electrode during operation. The arc power was supplied by a 4000-ampere, 0- to 250-volt, direct-current generator with continuously variable voltage control. The arc was initiated by a spark from a high-frequency, high-voltage igniter. For better arc stability, a ballast resistor of approximately 0.05 ohm was connected in series with the arc.

Before operation, the arc chamber was evacuated to 2.6 newtons per square meter, flushed with argon, evacuated to 2.6 newtons per square meter again, and then filled to the starting pressure in argon (99.9 percent pure). During operation, the pressure could be raised or lowered as needed.

The measurements taken were voltage, current, and electrode separation. Care was taken to ensure that the voltage was measured directly across the electrodes. The current was determined by measuring the voltage drop across a shunt. The electrode separation was determined by measuring the voltage drop across a 10-turn potentiometer the resistance of which was directly proportional to the cathode position. The pressure was measured with a strain gage transducer. At each setting of current, pressure, and electrode separation, care was taken to ensure steady-state conditions. The estimated limits of error were ±1 percent for arc voltage, ±1 percent for arc current, ±3 percent for gas pressure, and ±2 percent for electrode separation. Percent errors were of actual readings.

RESULTS AND DISCUSSION

Table I is a listing of the 32 measured data points. Analysis of table I indicates that voltage varies reasonably well as $P^{2/3}$, $L^{2/3}$, and I, where P is pressure, L is electrode separation, and I is current.

Figure 2 shows voltage-pressure characteristics at five different combinations of current and electrode separation. The data points indicate that voltage does increase with pressure to the two-thirds power.

Figure 3 shows voltage-electrode separation characteristics at three different combinations of pressure and current. The data points indicate that $L^{2/3}$ gives a good fit.

Figure 4 shows voltage-current characteristics at two combinations of pressure and electrode separation. The data points show that voltage increases slowly with current.

Analysis of figures 2 to 4 leads to a relation for voltage V, pressure P, current I, and electrode separation L of the type

$$V = A(LP)^{2/3} + BP^{2/3} + CI + D$$

TABLE I. - VOLTAGES MEASURED ACROSS A DIRECT-CURRENT

COMPACT ARC IN ARGON

Electrode separation, L		Pressure, P		Current, I, A	Measured voltage, V	Measured power, kW
in.	m	atm	N/m^2			
1	0.0254	1.09	1.09×10^5	600	31.1	18.7
		↓	↓	600	31.2	18.7
		↓	↓	800	32.4	25.9
		↓	↓	800	33.0	26.4
		↓	↓	1000	34.9	34.9
		↓	↓	1200	36.2	43.5
		2.00	2.00	600	37.1	22.3
		↓	↓	600	36.2	21.7
		↓	↓	800	38.6	30.9
		↓	↓	800	38.8	31.0
		↓	↓	1000	40.6	40.6
		3.00	3.00	600	41.5	24.9
		3.00	3.00	800	44.5	35.4
		4.00	4.00	600	46.5	27.9
		5.00	5.00	600	50.8	30.5
		5.00	5.00	800	53.6	42.9
		7.00	7.00	600	60.2	36.2
		10.00	10.00	600	71.9	43.1
1.5	0.0381	1.09	1.09×10^5	800	36.6	29.3
		2.00	2.00	↓	44.4	35.5
		3.00	3.00	↓	52.1	41.7
		5.00	5.00	↓	64.2	51.4
		7.00	7.00	↓	75.9	60.7
		10.00	10.00	↓	90.3	72.2
2	0.0508	1.09	1.09×10^5	800	41.9	33.5
		1.09	1.09	1200	46.0	55.1
		2.00	2.00	1200	54.2	65.0
		3.00	3.00	800	59.8	47.8
		3.00	3.00	1200	65.3	78.4
		5.00	5.00	800	74.2	59.4
		5.00	5.00	1200	81.0	97.2
		7.00	7.00	800	87.9	70.2

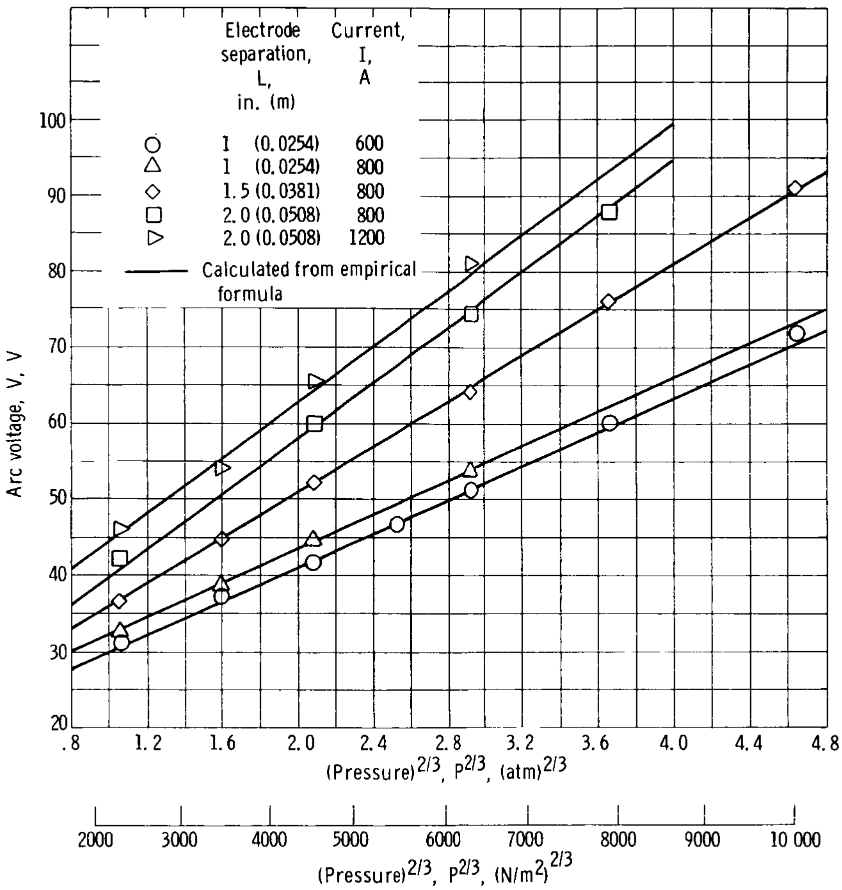

Figure 2. - Arc voltage in argon as function of pressure at five combinations of electrode separation and arc current.

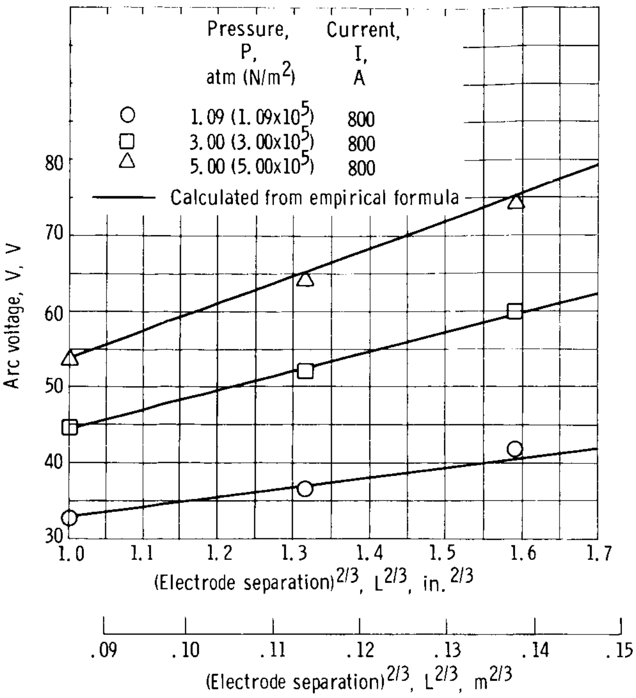

Figure 3. - Arc voltage in argon as function of electrode separation at three different combinations of pressure and arc current.

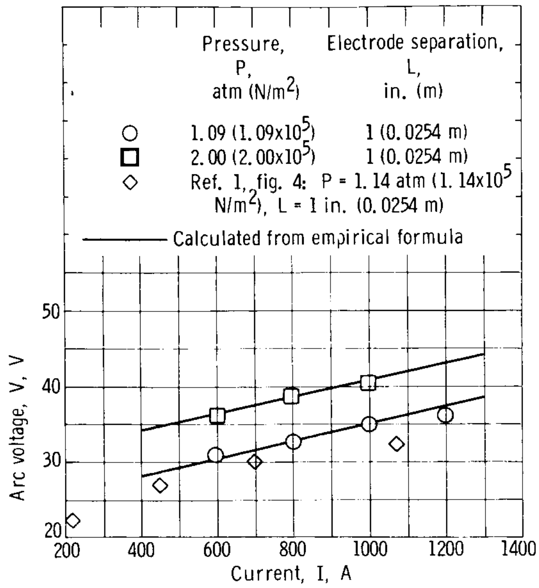

Figure 4. - Arc voltage in argon as function of current at two combinations of pressure and electrode separation.

A least squares fit of the data points tabulated in table I yields the following empirical formula

$$V = 12.4(LP)^{2/3} - 1.18\ P^{2/3} + 0.0116\ I + 11.7$$

where V is in volts, L is in inches, P is in atmospheres, and I is in amperes, or

$$V = 6.67\times10^{-2}(LP)^{2/3} - 5.48\times10^{-4}\ P^{2/3} + 0.0116\ I + 11.7$$

where V is in volts, L is in meters, P is in newtons per square meter, and I is in amperes. This relation fits the measured data within 5 percent. The solid lines plotted in figures 2 to 4 are calculated from the empirical relation.

Measurements from reference 1 of voltage against current at an electrode separation of 1 inch (0.0254 m) and a pressure of 1.14 atmospheres (1.14×10^5 N/m^2) are also plotted in figure 4. Above 400 amperes, the linear current dependence is observed to hold, although the voltages are 10 percent lower than the empirical formula predicts. The other references cited report a nonlinear current dependence below 400 amperes. Therefore, the empirical formula should be restricted to currents above 400 amperes. In subsequent testing, the empirical formula has been verified at currents up to 2000 amperes and pressures up to 4 atmospheres (4×10^5 N/m^2). The usable ranges of electrode separation and pressure may be considered to be those investigated in this report.

CONCLUSIONS

The variation of the voltage across an arc in argon with pressure, current, and electrode separation was measured in conjunction with work toward the development of a high power compact arc source. A relation was determined for the voltage across the arc as a function of these parameters in the ranges of 600 to 1200 amperes, 1 to 2 inches (0.0254 to 0.0508 m), and 1 to 10 atmospheres (10^5 to 10^6 N/m^2). This relation is valid within 5 percent from 400 to 2000 amperes and the electrode separation and pressure ranges just mentioned.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, March 22, 1968,
124-09-05-03-22.

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